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# Lubrication

A Technical Publication Devoted to  
the Selection and Use of Lubricants

## THIS ISSUE

Railroad Diesel  
Fuels and  
Lubricants



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# LUBRICATION

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Published by

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## Railroad Diesel Fuels and Lubricants

IF one were to stop now to write a history of railroading, the introduction and use of Diesel Electric locomotive power would no doubt be recorded as one of the most significant developments in this great industry. While the lonesome wail of the steam whistle and the puffing and snorting of the steam locomotive had become symbols of travel and the power to haul freight and passengers, it was only natural that the development of a more economical and efficient type of power would be adapted for railroad use.

Following a brief induction period after 1934 there was a phenomenal increase in the use of Diesel power, as illustrated in Figure 1. By 1952 the number of Diesel locomotives had exceeded the number of steam locomotives on domestic railroads, and if one were to gaze in the crystal ball and project the curve into the future, nearly complete Dieselization would be expected between 1960 and 1965. In 1954 Diesel electric locomotives accounted for 84% of freight gross ton miles, 86% of passenger train car miles and 90% of locomotive hours in yard switching service based on ICC statistics. Today it is estimated there are over 25,500 Diesel units representing an imposing 34,500,000 total horsepower.

The main incentives for rapid Dieselization of the railroads were lower operating costs, increased availability, and more flexible utilization of power. The Diesel engine burns fuel much more efficiently than the steam locomotive and a survey of many

railroads will show as much as 50% reduction in the cost of operation and maintenance compared to steam power. As the Diesel locomotive does not require as much time for servicing and overhauling, in many cases, it is available for useful work in excess of 90% of the time. It should be pointed out that these economies did not take place overnight but were the result of a tremendous amount of research and development on the part of the locomotive builders, railroads, and other supporting industries.

While the Diesel electric is now established as the basic type of power in the United States, considerable effort is being directed to reducing operating costs and improving unit performance. Thus, further increase in horsepower output per locomotive can be expected, and based on present developments, this will probably be accomplished by more intensive supercharging and higher engine speeds. This coupled with a trend to use lower cost and correspondingly lower quality fuels can be expected to place increasing demands on the lubricant to permit satisfactory operation.

### LUBRICATION

Continued advances have been made on engine design since the first units were placed in service. These advances have come about step by step in true engineering fashion, and the improvements have resulted generally in increased power output per

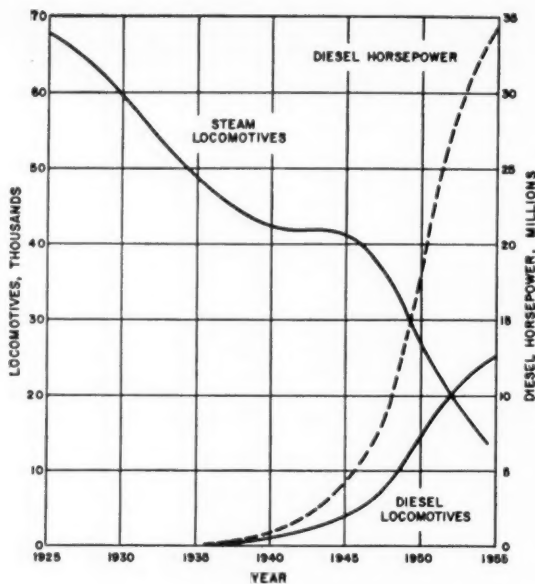


Figure 1 — Curves illustrating the growth of Diesel locomotive power compared with steam power.

cubic inch of displacement to meet the ever pressing demands for increased unit output. Locomotive manufacturers are not slowing down along these lines either. Improved manufacturing techniques along mass production lines, coupled with the use of materials that will withstand higher temperatures and pressures, are making it possible for further progress in Diesel locomotive development.

These continued advances have imposed several problems on lubricating oil performance including:

- Ring Sticking and Breakage
- Valve Sticking and Blowing
- Wear
- Metal Corrosion, Including Silver
- General Engine Cleanliness
- Viscosity Buildup and Oil Contamination

These problems vary in importance depending upon type of locomotive power: whether freight, passenger, or switcher; type of engine, whether 2 cycle or 4 cycle, supercharged, etc.; and how the power is operated and/or maintained. The current trend to burn lower cost fuels also influences the severity of these problems and introduces other factors which require careful consideration.

### Ring Sticking and Ring Breakage

Ring sticking and ring breakage problems are generally associated with improper maintenance or operation, although the type of fuel and lubricating oil can be important factors. Ring sticking is primarily related to ring temperature. Provided combustion is complete and ring temperatures are below 375°F., ring sticking is not likely to be a problem.

With increased horsepower outputs, however, ring sticking can become a problem if ring temperature increases in the range of 375°-450°F. In this range, the type of oil is important and heavy duty detergent oils or naphthene type are best. Above 450°F. all oils seem to carbonize. Occasionally the top ring is swept by hot combustion gases and burned clean in which case the second ring may stick. Ring sticking may also be caused by wavy or warped ring lands. If ring sticking cannot be eliminated by proper selection of lubricating oils then ring temperatures will have to be reduced by: increasing efficiency of jacket cooling system; increasing piston cooling; improving fit of rings in cylinders to eliminate blow-by; reducing peak loads. Other methods of correcting ring sticking are: reducing the amount of oil reaching the rings; increasing ring groove clearance; improving combustion. Ring sticking can also be due to cold, light load operation causing fuel varnish deposits which streak the piston in an irregular pattern easily identified. Control of ring temperature, which governs ring sticking is, however, primarily a question of design of pistons, rings and cylinders.

Ring breakage may be due to factors causing ring sticking in addition to: excessive side clearance causing unnecessary ring fluttering; excessive cylinder taper, causing ring flexing; hard carbon ash deposits non-uniformly located in ring grooves; combustion knock caused by improper timing or low cetane number fuels; continuous overload or overspeed operation. Operation in accordance with recommended procedures, combined with good maintenance, will reduce ring sticking and ring breakage to a minimum.

### Valve Sticking and Blowing

Several factors can influence exhaust valve sticking and blowing, the most important of which are conditions leading to high operating temperatures. Causes of valve sticking may include insufficient valve stem to guide clearance at operating temperature; cocked or bent valves; scratched or nicked valve stems from improper handling; deposit build-up on valve stems near the end of the valve guide due to high valve temperatures. Assuming the valves are properly installed, the use of a heavy duty lubricating oil will generally correct valve sticking from deposit buildup. Increased horsepower outputs and speeds tend to increase valve temperatures and place increased demands on exhaust valve cooling.

### Wear

Wear of piston rings and cylinder liners is a result of corrosion, erosion and abrasion. The degree that these mechanisms influence wear will



depend to some extent on the operating conditions encountered. Wear due to corrosion means chemical attack of piston rings and cylinder liner surfaces by vapors or acids. These corrosive materials form from products of fuel combustion, some of which do not have an opportunity to exhaust from the cylinders. The extent these corrosive materials are formed, depends on fuel quality, completeness of combustion, jacket cooling temperature, exhaust back pressure and lubricating oil quality. Fuel quality and completeness of combustion go hand in hand. For example, it is easier to completely burn the lighter distillate fuels than heavy residual oils. Fuel contaminants such as sulfur and nitrogen compounds also can form corrosive materials during combustion, particularly in the presence of water vapor, with low jacket water temperatures. Trace elements in residual fuels such as vanadium, sodium, etc. are likewise a source of potentially corrosive as well as abrasive materials. Maintaining jacket water temperatures sufficiently high is an important factor in reducing this type of wear, also exhaust back pressures should be as low as practicable. Heavy duty type lubricating oils have helped minimize corrosive wear; however, the extent such oils will combat the effects of corrosion from the use of residual type fuels is yet to be clarified. Abrasion and erosion are influenced by many of the same factors that affect corrosive wear, in addition to air cleanliness and combustion chamber deposits. Properly filtered air is one of the most important factors in decreasing abrasion wear. Figure 2 illustrates the effect of sand particles separated from oil groove deposits on liner scratching. Impingement type air filters using a petroleum product as a dust catching medium are widely used, as well as centrifugal types which separate solid particles from the air by centrifugal force. Regardless of the type of filter used, it should be given proper attention to maintain its effectiveness.

## Engine Deposits

From a practical consideration, engine deposits can be divided into two categories—those that cause engine malfunctioning and those that do not. While engine cleanliness is a desirable objective, the engine itself is not concerned unless deposits interfere with its normal breathing or digestive functions. Varnish or lacquer films which occasionally form on cylinder walls, piston skirts, crankshafts and connecting rods, for example, do not as a general rule impair engine operation. Actually, such thin deposits can be beneficial in that they serve as a protective film against rusting or corrosion during periods when the engines are out of service. On the other hand, deposits which accumulate in cylinder ports, on valves, in piston ring grooves and in combustion chambers are objectionable and if not guarded against can lead to operating troubles.

There are three different basic types of deposits which may form in an engine—oil carbon, oil oxidation and oil water mixtures. The usual engine deposit may combine two or all three of these. The *oil carbon type* is usually due to soot from incomplete combustion. This can be related to fuel quality, poor injection, restricted air supply, overloaded condition, low jacket temperatures and worn piston rings and liners. These factors should be checked when encountering this type of deposit. Use of a detergent heavy duty oil will reduce the effects of fuel soot deposits in addition to improved filtration and more frequent oil changes. The *oil oxidation type deposit* is usually due to high oil temperatures. To reduce oil temperatures: check cooling system, fan, radiators, hose connections, and scale in water jackets; lower jacket temperatures; clean oil cooler. Other methods for reducing this type sludge are: drain oil more frequently; use higher cetane, lower sulfur fuel. The use of a heavy

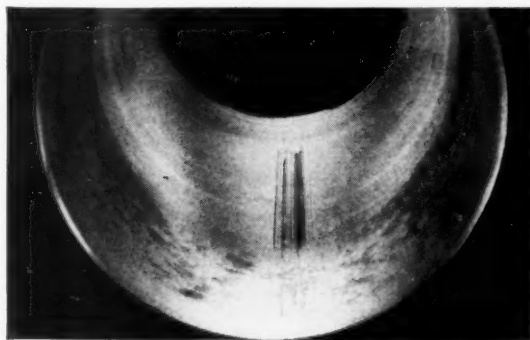
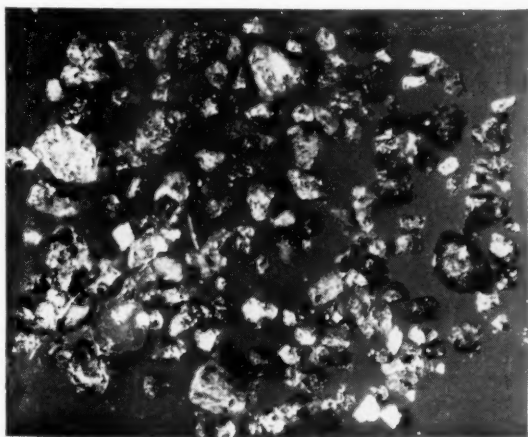


Figure 2 — Photographs illustrating the effect of sand (left) removed from piston oil ring deposit on cylinder liner scratching.

TABLE I  
PHYSICAL PROPERTIES — BEARING MATERIALS

Bearing Metal	Load Carrying Capacity (a)	Minimum Shaft Hardness- Brinell	Fatigue Strength (a)	Anti- Seizure (a)	Conform- ability and Embed- dability (a)
Lead or lead-tin coatings	4	(b)	2	1	2
Lead-base babbitt	5	(b)	3	1	1
Tin-base babbitt	5	(b)	3	1	1
Silver-hardened lead	4	(b)	2	1	1
Arsenic-hardened lead	4	(b)	2	1	1
Calcium-hardened lead	4	(b)	2	1	1
Cadmium	4	200-250	2	1	1
Copper-lead	3	250-300	2	2	2
Silver	1	300	1	2	2
Aluminum	2	300	2	2	3
Lead-bronze	1	300	1	3	3

(a) Relative ratings — 1 being best. (b) Not important.

duty oil will reduce this type of deposit; however, with increased power outputs, it may be necessary to increase piston cooling and increase crankcase capacity. *Oil water type deposit* is usually due to water contamination, low crankcase oil temperature or poor crankcase ventilation. Checking crankcase vent lines and increasing jacket water and oil temperature should reduce this type sludge. Steps should be taken also to correct any water leaks.

### Bearings

Improvements in bearing design and metallurgy have been necessary to withstand increased loads and temperatures in higher output engines. The development of stronger bearing materials has also placed increasing demands on the lubricating oil to provide satisfactory lubrication and corrosion protection with the various type bearings used. Improvements in bearing design include the development of precision type bearings with increased attention given to bearing clearances, oil grooving, oil flow and heat dissipation for the loads and operating conditions encountered. The stronger more fatigue resistant bearing materials used in railway Diesel engines includes copper-lead, silver, aluminum and lead-bronze types. Physical properties of these materials are shown in Table I. While these materials have high load carrying capacities, it will be noted their conformability, embeddability and antiseizure characteristics are not as good as the babbitt type. Accordingly, different alloys may be combined to obtain the optimum characteristics of each material as illustrated in Figures 3 and 4. Harder shafts are usually employed with these higher strength bearings and the oil must be adequately filtered for best performance.

From a practical standpoint, the aluminum and lead-bronze bearings are relatively non-corrodible. Copper-lead and silver bearings are, however, subject to corrosion depending on the type oil and service conditions encountered. In the copper-lead bearings, unless the oil is suitably inhibited, the lead phase may be dissolved by the lower molecular weight organic acids which result from oil oxidation. An example of this corrosion is illustrated in Figure 5. Note that the grey lead areas have been removed resulting in weakening of the bearing structure which can lead to eventual failure. The

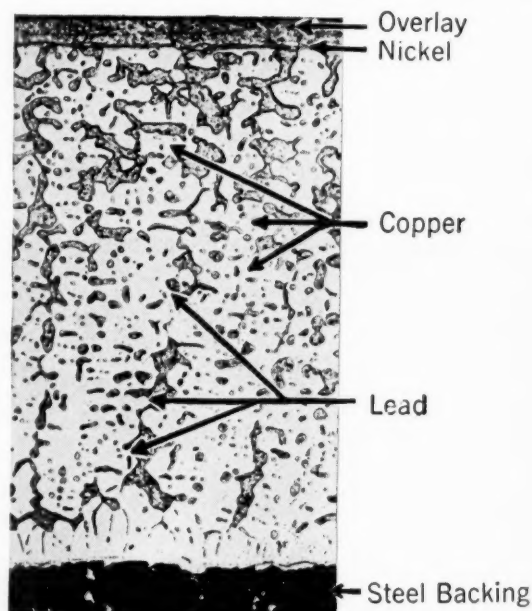


Figure 3 — Cross-section of tri-metal copper-lead bearing with lead-tin alloy overlay (150X).

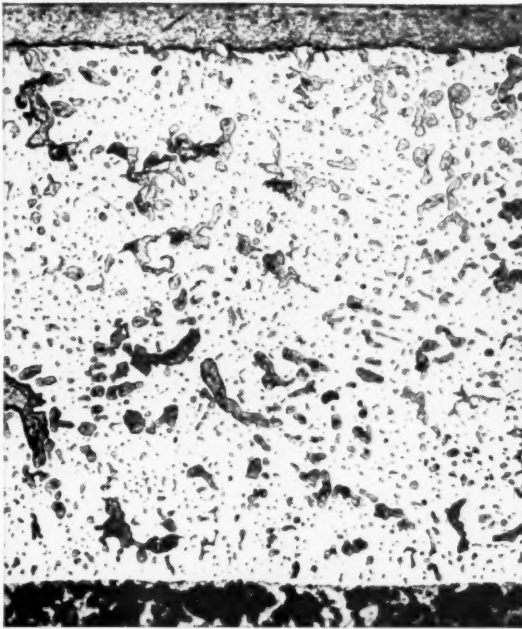


Figure 4 — Cross-section of lead-bronze bearing with overlay (100X).

presence of water contamination in the crankcase oil can also adversely affect lead corrosion. For silver bearings, the corrosion mechanism is much the same as household silver tarnishes. Here the chemical reaction involves the conversion of silver to silver sulfide. In general, straight mineral oils even when oxidized will not corrode silver. Oils diluted with high sulfur fuel and oxidized may corrode silver due to the presence of sulfur compounds. Certain additives which protect against corrosion of copper-lead and other alloy bearings may also react with bushings made of silver. An example of this is shown in Figure 6. Excessive temperatures can adversely affect corrosion as well as reduce the strength of bearings, and bearing temperatures should be kept as low as practicable consistent with satisfactory operation. From this brief discussion, it can be seen the development of heavy duty oils for higher output engines requires a careful balance of additive components to provide satisfactory lubrication and corrosion protection for all types of bearings used.

### Oil Performance

Lubricating oil performance depends on several factors; one of the most important in high output engines is temperature. If temperatures are too low, usually below 140°F., the oil may become contaminated with condensed moisture which can lead to the formation of deposits from oxidized oil and partially burned fuel materials.

Low temperatures also increase viscosity with resultant effect on friction and reduced filtration

efficiency. Excessively high temperatures can result in the formation of both soluble and insoluble oxidation products which can lead to increased viscosity and the formation of varnish, lacquer and coke-like deposits.

It has been generally observed that a properly refined oil will not oxidize appreciably below 200°F. Above this temperature, however, oxidation is more rapid and the rate depends on such factors as the presence of metallic catalysts, soluble metal compounds, water, degree of aeration and temperature and time of exposure. The incorporation of suitable additives will inhibit these oxidation effects, however, there is a limit to the effectiveness of these materials. Figure 7 illustrates the effect of crankcase temperature on oil oxidation using data obtained from a railroad type Diesel engine. As a general rule, crankcase oil temperatures in the range of 160° to 200°F. will provide the best performance with heavy duty type oils used in railway Diesel engines. Continued operation above these temperatures will require more frequent drain periods and increased maintenance. The temperature and time the oil is exposed to hot surfaces—for example, the undersides of pistons—also increases oil deterioration rates. Accordingly, higher output engines will probably require increased circulation of piston cooling oil and possibly increased crankcase oil capacity and larger oil coolers.

In addition to temperature effects, the accumulation of oil contaminants such as unburned fuel soot materials, dirt and dust, fuel dilution, metal particles, water and water treating materials affects oil performance. Suitably designed and maintained filters are therefore necessary to keep filterable contaminants as low as possible at all times.

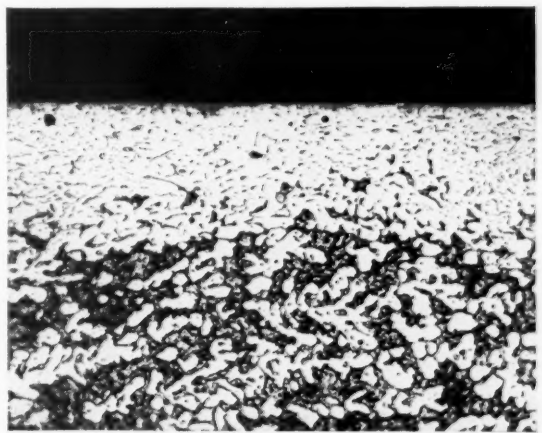


Figure 5 — Corroded copper-lead bearing showing lead removal near surface followed by pounding down of copper filling in the voids.

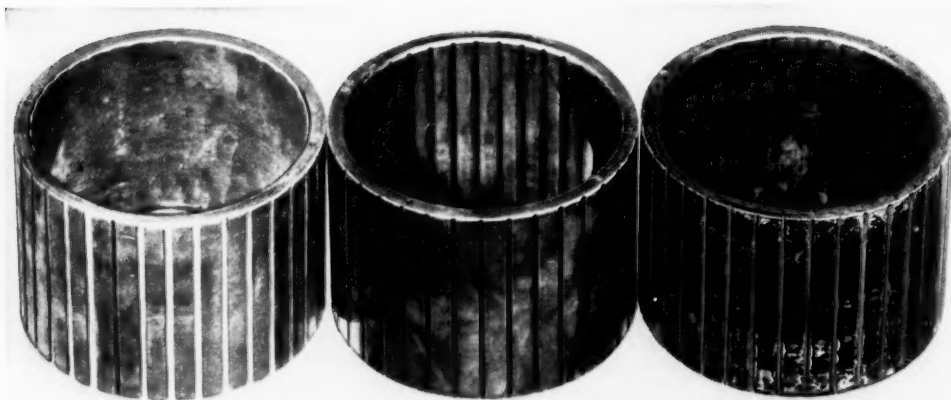


Figure 6 — Silver connecting rod bushings showing the effects of additive reactivity with different type heavy duty lubricating oils.

### Railway Diesel Lubricants

When the first Diesel locomotives went into service, the engines were lubricated with straight mineral oils generally of the naphthene variety. Such oils performed extremely well. These oils still give a very good account of themselves in later more modern equipment in certain operations. To lubricate the modern Diesel electric locomotive operating in heavy duty service to the best advantage, oils with properties enhanced along certain lines are used. Characteristics which a good railway Diesel oil must possess include:

1. Oxidation stability to reduce deposit formation and withstand viscosity buildup.
2. Adequate film strength to reduce wear of moving parts to a minimum.
3. Corrosion resistance to prevent acid attack of metals, particularly those used in bearings and bushings.
4. Dispersion and detergency to hold contaminating materials in suspension or solution thereby reducing the tendency to deposit out on engine parts.
5. Rustproofing sufficient to prevent rusting of

metal surfaces during locomotive engine shutdown or temporary storage.

Over the last several years, petroleum research laboratories have learned a great deal more about these lubricating oil characteristics. They know, for example, how to improve certain properties without interfering with the others in order to provide an oil which will successfully handle a specific lubrication assignment. With regard to Railway Diesel lubrication, improved oils have come into existence by:

1. Selecting base stock from best available crude sources.
2. Refining with processes which will remove all undesirable properties.
3. Incorporating chemical additives\* that will enhance desirable characteristics in a finished oil.

After the final formulation of an oil has been decided upon, it has to be tested extensively and exhaustively in the laboratory under a great variety of conditions, even to the extent of evaluation in full scale Diesel locomotive engines. (See Figures 8 and 9.) Following this, hundreds of thousands of miles of satisfactory field experience in all types of locomotive Diesels in all types of service must be accumulated before the oil can be considered as entirely acceptable.

### FUELS

One of the initial claims made for Dr. Diesel's engine was that it could burn a wide range of inexpensive fuels. In fact it is understood one manufacturer's early fuel specification stated that "This engine will burn any liquid fuel that will flow by gravity through a 1/2" pipe 10 feet long." Needless to say there has been considerable change in specifications since that time.

With continued refinements in engine design in-

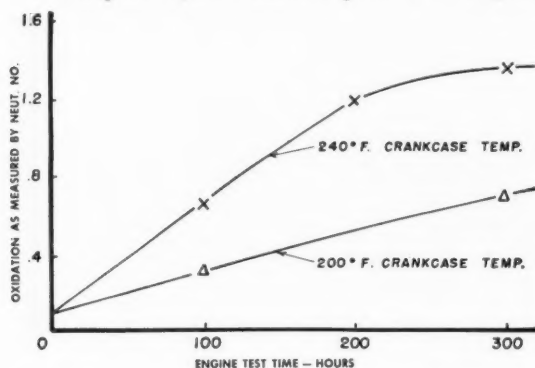


Figure 7 — Effect of crankcase temperature on oil oxidation. Data obtained in a railroad type Diesel engine.

\*A more detailed discussion of additives is given in "Lubrication", Vol. 38, No. 1, 1952.



## LUBRICATION

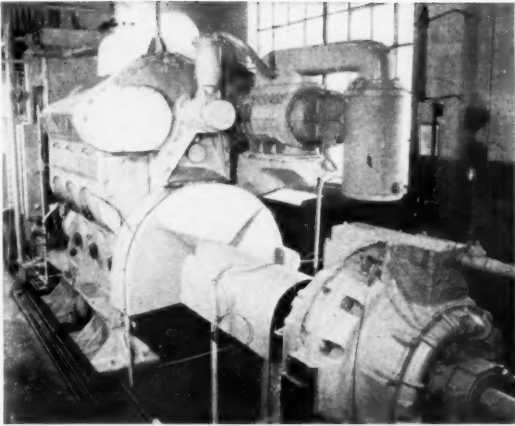


Figure 8 — A full-scale, six-cylinder, 660 HP, 567C Electro-Motive railroad locomotive Diesel engine set up in the laboratory for study of fuels and heavy duty lubricating oils.

cluding increased speeds and loads and solid injection systems, it was found that the engines gave good performance on a clean burning distillate fuel having good ignition and handling characteristics. Consequently, most of the railroad type Diesel engines were designed to handle and burn a relatively good quality distillate fuel. Until recent years, practically all of the fuel burned in Railway Diesel engines was made from straight run distillates. Now, because of

the greatly expanded use of the Diesel engine, it is not possible to supply enough straight run Diesel fuel to meet the demand. To increase the supply, the higher quality cracked distillates are blended with straight run stocks. When suitable components are used, the resulting fuel provides satisfactory engine operation and satisfactory storage stability and handling characteristics.

As previously mentioned, the railroads are continually studying ways to improve economy and utilization of power. One of the more significant studies being made is the use of lower cost or "Economy" Diesel fuels. This is a natural step since railway Diesel fuel costs may represent as much as 65% of the total cost of operating a locomotive. The railroads will probably consume over 3.5 billion gallons of fuel in 1955. Substantial economies might be realized provided the lower cost and correspondingly lower quality fuels are generally available and provided their use does not introduce added maintenance and operating difficulties which would offset any savings in fuel costs.

### Types of Fuels

At the present time, the majority of fuels being burned in American Diesel locomotives may fall into five general categories, listed in the order of their relative costs.

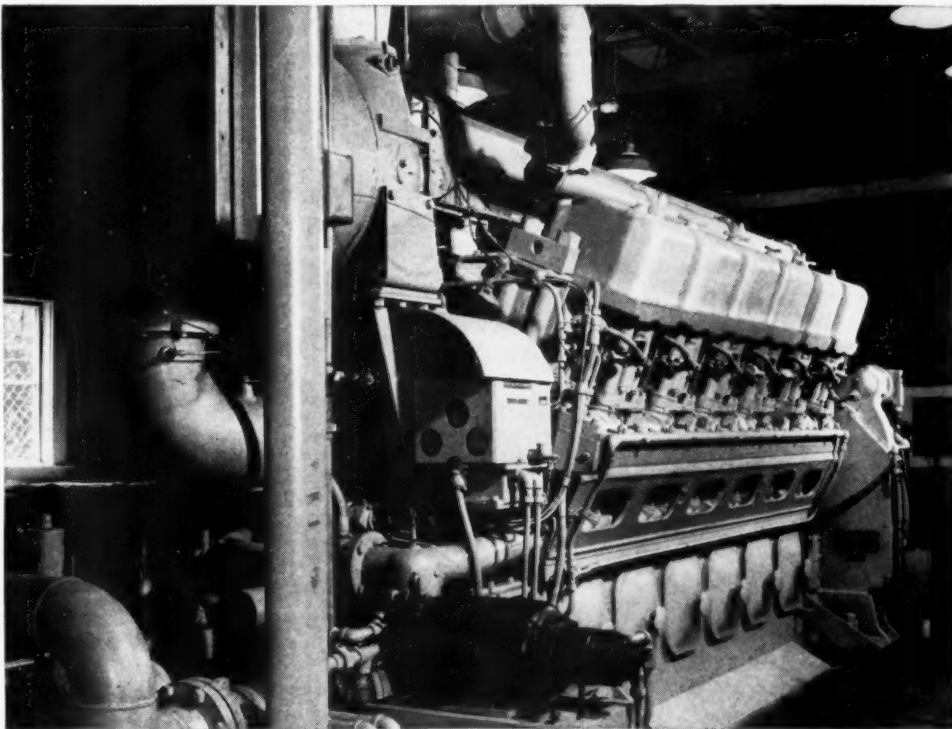


Figure 9 — A full-scale, 12-cylinder, 1600 HP Model 244 Alco Products railroad locomotive Diesel engine set up in the laboratory for study of fuels and heavy duty lubricating oils.

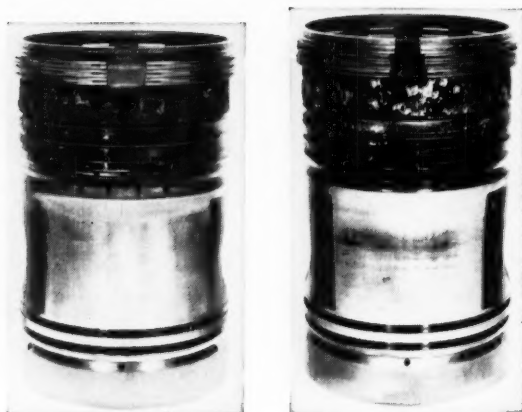


Figure 10 — Condition of pistons and rings after 500 hour full-scale laboratory engine tests using 50 (left) and 40 (right) cetane Diesel fuels.

### RAILROAD DIESEL FUELS

1. Diesel Fuel No. 1\* (50 Plus Cetane Number)
2. Diesel Fuel No. 2\* (45-49 Cetane Number)
3. Diesel Fuel No. 3\* (40-44 Cetane Number)
4. Economy Fuel (35-39 Cetane Number)
5. Blended Fuel (Blends of Residual and Distillate Fuels)

\*(Also classified by some railroads as Grades A, B, C, etc.)

The first four grades are 100 percent distillate fuels and with the exception of the lower cetane number of the Economy Fuel, their range of characteristics generally falls within the ASTM classification for No. 2D Diesel fuels.<sup>1</sup> There are, however, some heavier grades of Economy Fuels being considered, including heavy straight run distillates and heavy cracked distillates which would fall outside the ASTM D2 classification. The Blended Fuels generally fall within the ASTM classification for No. 4D<sup>1</sup> Diesel fuel; however, this depends upon the amount and type of residual component.

As a general rule, the lower cetane fuels contain increasing amounts of cracked distillates from catalytic refining processes. These processes are widely used throughout the petroleum industry to increase the yields of high octane gasoline and middle distillate fuels from a barrel of crude oil to meet the demands for these products. The cost of the lower cetane fuels is, therefore, closely related to their value as recycle or charging stocks to these processes or to their value as blending components in other products. In order to preserve any economical advantages, the lower cetane fuels will generally be less uniform and their specifications more liberal. Their availability and uniformity will also tend to vary with individual refineries, geographical location, quality of crude being processed and variations in

seasonal demands for different fuels. It should also be recognized that the supply of additional fuels not already on the market requires additional storage and handling facilities involving dual investment which adds to the overall cost of such fuels.

### Fuel Performance Characteristics

The first two grades of fuel in the 45 to 50 plus cetane range are widely used and their good performance characteristics in railroad Diesel locomotives are well known.

Considerable experience has been obtained with the No. 3 type 40-44 cetane fuels with generally satisfactory results. Less experience has been obtained with the 35-39 cetane Economy grades in the ASTM No. 2 distillation range, although experience to date has not shown any serious operational difficulty. These fuels may be a blend of cracked distillates with straight run fuels or 100% cracked distillates, which results in a lower API gravity and higher BTU content per gallon. The fuels may have a wider distillation range and higher sulfur and carbon residue values than the 45 and 50 plus cetane fuels. Stability and compatibility are also factors that must be considered.

Extensive CRC full-scale field service tests with fuels having 40 cetane number, 1% sulfur and 700° F. end point indicate such fuels can be used without any serious operational difficulties. When the final report on these tests is completed, further information should be available as to the possible effect on wear, deposits, etc. Figure 10 shows the condition of pistons after 500 hour severe cycling tests in a full scale laboratory test engine using 50 and 40 cetane fuels having characteristics listed in Table II. From a cleanliness standpoint, no significant differences were found between the two fuel tests with the same heavy duty railway Diesel lubricating oil. In addition, there was no evidence of increased oil deterioration with the higher sulfur content 40 cetane fuel, although service life of the oil filters was shorter. Economy fuels in the 35 cetane range

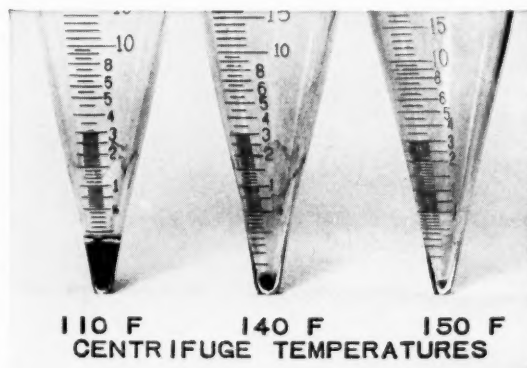


Figure 11 — Effect of temperature on the amount of waxes and residues centrifuged from a residual type fuel.

<sup>1</sup>Tentative classification of Diesel Fuel Oils ASTM Designation: D975-53T.

## LUBRICATION

TABLE II  
ANALYSIS OF FUELS USED IN LABORATORY ENGINE TESTS

	50 Cetane Distillate Fuel	40 Cetane Distillate Fuel	Residual Distillate Blend
Gravity, °API	34.2	33.2	32.6
Flash, PM °F.	172	152	164
Viscosity, SSU @ 100°F.	37.3	32.4	39.0
Pour, °F.	0	-40	-15
Sulfur, %	0.66	0.94	0.86
Carbon Residue on 10% Residuum % —	0.05	0.25	1.44 <sup>a</sup>
Distillation, °F.			
10%	445	434	417
50%	527	457	499
90%	623	507	705
End Point	674	574	<sup>b</sup>
Cetane No.	51	40	45
Ash	Nil	Nil	.009
Vanadium (Parts per Million)	—	—	45
Sodium	—	—	2
Nickel	—	—	5

<sup>a</sup>On whole sample. <sup>b</sup>Not obtained fuel cracked at 710°F.

may present some starting difficulties at low ambient temperatures and possibly increased smoking while idling; otherwise, operation at part and full loads should be satisfactory. While additional experience will be required to evaluate the overall economics, at the present time, the use of the 40-44 cetane No. 3 grade or the 35-39 cetane Economy fuels may be the most logical approach to the use of lower cost fuels without having to resort to extensive engine modifications or changes in fuel handling practices and equipment. Some of the light and intermediate cracked distillates may not be as storage stable as conventional fuels and the use of larger, more efficient fuel filters may be desirable. Stability characteristics can be improved either by additional processing or use of additives at slight increased cost. Additional processing could also be effective in reducing sulfur content and increasing cetane number; however, this would tend to bring the quality and price in line with regular Diesel fuels. Also such fuels would have a high value as catalytic charge stocks.

Heavier grades of Economy fuels being studied or tested by some railroads may include the heavier vacuum distilled gas oils, heavy cracked gas oils or blends of these products with lighter distillates. These products have still lower API gravities and correspondingly higher BTU content per gallon; however, due to their higher pour points (up to 85-90°F.) and viscosities (up to 1050 SSU @ 100°F.) such fuels will generally require the instal-

lation of necessary heating equipment on locomotives, as well as in storage facilities, lines, etc. to insure satisfactory pumpability. Heating equipment may also be required to reduce the viscosity at the injectors to obtain suitable spray characteristics for satisfactory combustion. As such fuels may be subject to wide variations in viscosity, automatic controls will be required to insure correct viscosity at the injectors. Depending on the type of heating system used, controls will also be required to prevent over-heating of the fuel to avoid excessive deposits and plugged lines. Larger fuel filters will be required and filter heating equipment may be necessary to prevent rapid plugging of elements by wax and residues. Figure 11 illustrates the effect of increased temperatures on decreasing the amount of waxes and residues centrifuged from a fuel.

The use of high pour, heavy distillates in Railway Diesel engines is rather limited. There is some experience, however, to indicate such fuels can be burned very well, particularly at the higher loads and speeds, if properly heated. Increased smoking and deposits may be encountered at low speeds and idling, which could place increased demands on lubricating oil requirements. Depending on ambient temperatures, an auxiliary fuel system may be required to flush out the main fuel system with light fuel during shut down to prevent the heavy fuel from solidifying in the lines. In this regard, some tests are being made with auxiliary fuel systems equipped with special valves which will automati-



Figure 12 — Condition of pistons and rings after 300 hour full-scale laboratory engine tests using a 50 cetane reference fuel (left) and a residual-distillate blended fuel (right).

cally switch from heavy to regular fuel at a predetermined throttle position. These so-called "dual-fuel" systems are designed to permit automatic operation on heavy fuel at the higher speeds and loads, switching to regular Diesel fuel at the time throttle position is reduced to third notch or lower. This is in the slow speed and idle range where combustion of the heavy fuel would be more critical. Further experience will be necessary to evaluate the performance and reliability as well as the economics of this system in actual operation. It can be seen from the foregoing that several factors must be included in considering the overall economy of these heavier distillate fuels.

### Residual Fuels

The successful use of residual fuels in railway Diesels would be expected to result in the best economy from a fuel cost standpoint. Unfortunately, the characteristics of these fuels make them even less suitable as railroad Diesel fuels than the heavy distillates. In addition to wide variations in gravity, viscosity and pour point, these fuels may contain appreciable amounts of sulfur, carbon residue and metallic ash constituents, including vanadium and sodium which can adversely affect engine operation.

Some railroads are exploring the possible use of residual fuels using a "dual-fuel" system discussed in the previous section on heavy distillate fuels. However, it appears that increased problems of handling, heating, and filtration in addition to problems of combustion, deposits, wear, corrosion, etc. will require considerable study before the use of straight residual fuels is considered practical.

### Residual Distillate Blends

To reduce the severity of problems indicated with straight residual fuels, some railroads are either testing or studying the use of residual fuels blended with lighter distillate fuels. This results in a lower

viscosity fuel that is easier to handle; however, some blending components may not be compatible which could lead to fuel filtration problems and possible injector difficulties unless the blends are carefully controlled. While increasing the amount of the lighter blending component reduces the problems indicated for straight residual fuel, the cost is correspondingly increased. Therefore, it can be seen considerable experimentation will be required to determine the optimum fuel characteristics that will provide the best overall economy. Depending on the nature of the blending components used, suitable fuel heating equipment as well as "dual-fuel" systems may also be required in the handling and burning of residual distillate blends.

Figures 12 and 13 show the condition of pistons from 300 and 500 hour laboratory tests in full scale railway Diesel engines burning a residual distillate blended fuel for comparison with similar tests using the 50 cetane fuel listed in Table II. The 300 hour tests were run at full load and speed throughout. The 500 hour tests included 400 hours operation under severe cycling conditions, each cycle consisting of 2 hours full load and speed alternating with one-half hour at idle, followed by 100 hours at full load and speed. A medium detergency level heavy duty lubricating oil was used for each test. No serious operational difficulties were encountered in either series of tests which could be attributed to the fuels or lubricants used. It was, however, necessary to install larger capacity fuel filters and to change elements at frequent intervals to avoid fuel starvation from plugged elements. No unusual deterioration effects were noted in the condition of the used lubricating oil except in one test a sharp reduction in ash content was observed after the crankcase oil became diluted with approximately 2% residual distillate



Figure 13 — Condition of pistons and rings after 500 hour full-scale laboratory engine tests using a 50 cetane reference fuel (left) and a residual-distillate blended fuel (right).



## LUBRICATION

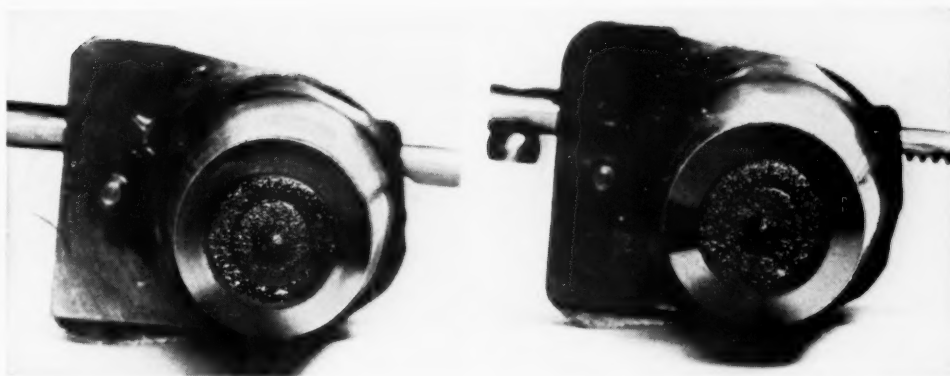


Figure 14 — Deposit build up on injector tips using residual-distillate blended fuel.

fuel. In general, the tests showed some increase in deposits and wear would be expected with this particular type of residual-distillate fuel in railroad service. Some improved cleanliness would be expected with a higher additive level oil; however, additional field testing will be required to determine if such oils will improve performance from a wear standpoint.

In both tests, the engines were able to maintain full power outputs with clean exhausts, indicating satisfactory injector performance. There was, however, increased deposit buildup on fuel injector tips, as illustrated in Figure 14, indicating increased injector maintenance will be required with the residual distillate blends. The continued buildup of adherent type deposits would not only affect fuel spray characteristics and result in poor combustion efficiency but would also contribute to increased engine deposits and wear. With the use of lower quality fuels, good combustion characteristics become an increasingly important factor. Some modification in fuel injector design may be required to provide satisfactory spray characteristics with the heavier fuels. Also, changes in fuel injection rates and timing may be desirable to compensate for ignition characteristics of low cetane number fuels.

The most significant differences between the two fuels were corrosion and pitting of the exhaust valves and seats with the residual-distillate fuel as illustrated in Figure 15. In the 300 hour run, only the top of the exhaust valve head was affected; however, in the 500 hour test, both the exhaust valve faces and seats were attacked. Examination of the valves and deposits indicated the corrosive attack was due to the small amounts of vanadium and sodium present in the residual component of the fuel. These trace elements, even when present in

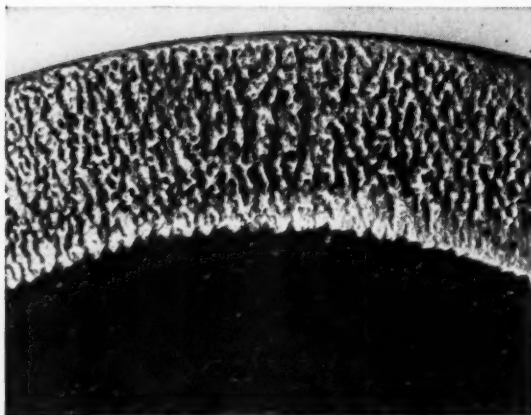
TABLE III

METAL	PPM	
	Before Centrifuging	After Centrifuging
Vanadium	390	390
Iron	3	3
Nickel	42	42
Sodium	4	4

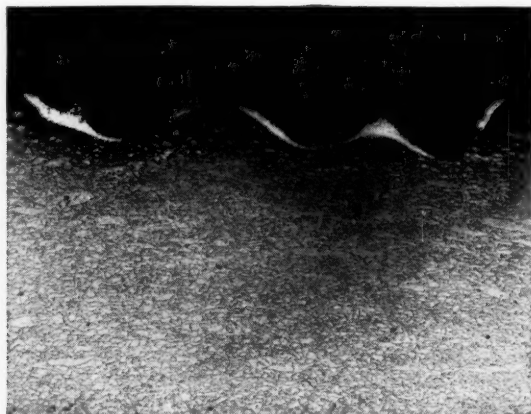
small amounts, can be quite corrosive to certain metal parts when the temperature of such parts exposed to the combustion gas stream exceeds  $1200^{\circ}\text{F}.$ <sup>1 2</sup> Accordingly, the most severe corrosive effect of these trace elements would be expected under high temperature conditions and during maximum power outputs. The use of special corrosion resistant materials may be effective in reducing this type of attack, or it may become necessary to reduce horsepower outputs. Under certain conditions, possibly during incomplete combustion, these elements may also combine to form glass-like slag deposits which in some cases are hard enough to scratch steel of 670 Brinell hardness. Such deposits can result in abrasion and wear of piston rings and liners if lodged in ring grooves and ports. These trace metals are generally present in a combined state in varying amounts from several different crude sources and are practically impossible to remove from the fuel by normal centrifuging or filtering. Table III shows centrifuging a sample of residual fuel had no significant effect in reducing the amount of vanadium and other trace elements.

It is possible that special lubricants, the use of fuel additives or special fuel treatment may be employed to remove or pacify these trace elements; however, until their effectiveness can be proven, the presence of these elements may be one of the major limiting factors in the use of residual fuels or their

<sup>1</sup> "Residual Fuel Oil Ash Corrosion" by B. O. Buckland, C. M. Gardener and D. G. Sanders, ASME Paper #52-A-161, 1952.  
<sup>2</sup> "Evaluation of Corrosion Resistance For Gas-Turbine-Blade Materials" by W. E. Young, A. E. Hershey and C. E. Hussey, Jr., ASME Paper #54-A-215, 1954.



Corrosive attack on exhaust valve head.

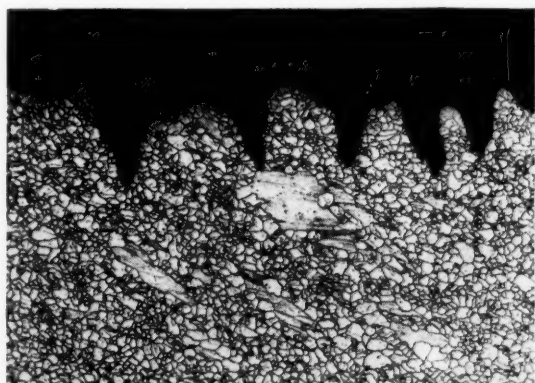


Cross-section through exhaust valve head (75X).

## 300 HOUR TEST



Corrosive attack on exhaust valve face.



Cross-section through corroded area on exhaust valve face.

## 500 HOUR TEST

Figure 15 — Corrosion and pitting of exhaust valves due to trace elements in residual-distillate blended fuel.

blends. Any special treatment would also increase the cost of these fuels.

In summary, good quality fuels are available which will give satisfactory performance in railroad Diesel engines. Considerable progress is being made in the use of lower cost fuels; however, careful attention must be given to the several factors involved in the handling and burning of corresponding lower quality fuels to assure any savings in fuel costs will not be offset by increased costs of maintenance and handling. Several problems will necessarily require further research and testing which can best be attacked through the continued cooperation of the railroads, engine builders and petroleum companies to determine the most economic solutions. With the trend to increased horsepower outputs and speeds, the use of higher quality fuels should not be overlooked as a solution to the best overall economy.

## CONCLUSION

The development of Diesel engines has given the railroads a more economical and efficient type of power and considerable efforts are being directed to reducing operating costs and improving unit performance. This, coupled with the trend to the use of lower cost fuels has placed increased demands on the lubricant to permit satisfactory operation. Over the years, the petroleum industry has demonstrated its ability to supply fuel and lubricants required by its customers, and the successful record is the result of the fine cooperative spirit existing between the railroads, locomotive builders and petroleum companies. As further developments are made in prime movers such as gas turbine, free piston engines and atomic power, it can be expected the railroads will determine their economic advantages.

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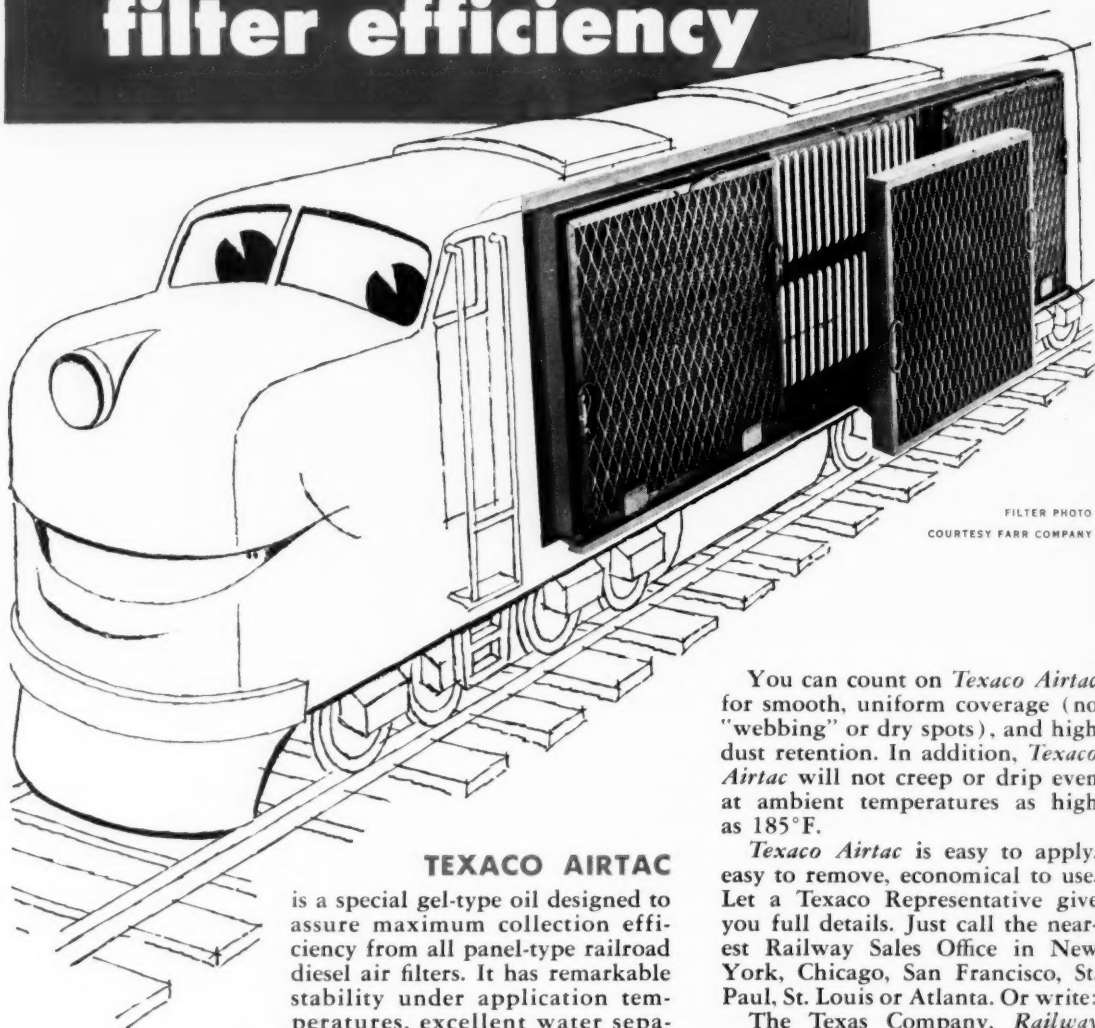
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